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ADDRESS

DELIVERED BY

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IN THE

SECTION OF ASTROPHYSICS

AT THE

Congress of Arts and Sciences at St. Louis,

ON

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ADDRESS delivered by H. H. TURNER, D.Sc., F.R.S., Savilian Professor of Astronomy in the University of Oxford, in the Section of Astrophysics at the Congress of Arts and Sciences at St. Louis, on Wednesday, Sept. 21, 1904, at 4 p.m.

The European astronomers here present have to thank the organizers of this Congress for much more than their hospitable invitation to attend it, and the opportunities thus afforded of meeting here in St. Louis so many men eminent in there own or other branches of knowledge: over and above this they owe to them opportunities of seeing the great observatories which have developed so rapidly in this country during the last quarter of a century, and of admiring at close view the resources and the work of which the fame had already reached us across the Atlantic. This is not the time or the place for any account of what we have seen and learnt; but not to put on record a word or two of appreciation of the great works accomplished, and of that munificence on the part of American citizens which has rendered them possible, would be indeed an omission. We from Europe are, in at least one respect, critics well qualified to judge whether an adequate return is being obtained for endowments such as have recently fallen to the happy lot of American astronomers, for most of us have had some practice in the use of such endowments—*hypothetically*. The constraints of more modest equipments have inevitably suggested plans for work on a larger scale—observatories-in-the-air which our imaginations fill with beautiful and novel apparatus, where the preliminary trials are always successful and no mistakes are made. We come to you accordingly prepared to judge what we see by comparison with a very high standard, and you may well be content with the commendation which we offer unstinted. We

rejoice to think that, in the presence of the new and vast possibilities opened up by the gradual accumulation of facts during the last century, by the invention of the spectroscope, and by that of the photographic plate, Astronomy should be so fortunate as to receive valuable aid just at a time when it is so urgently needed. It may be well for us to glance for a moment on the other side of the picture, and to wonder what would have been the course of events if this timely aid had not come. How would Astrophysics, the new-born child of Astronomy, have been nourished? We can scarcely think that it would have been allowed to want for nutriment, but whatever was given to it must inevitably have been withdrawn from the scanty stock of the parent science; either parent or child, it not both, must have shown signs of starvation. This danger is by no means entirely averted even yet; the needs of both, especially of the youthful Astrophysics, are increasing daily, as in the case of any other young and healthy organism. The future is not free from anxiety; but that the present is not actually a time of distress is largely due to the generosity displayed towards our science on this side of the Atlantic.

I am tempted to make a remark regarding another science, suggested by the above considerations in conjunction with incidents of travel. No one can cross this great continent and note the extraordinarily rapid spread of civilization, without feeling his interest drawn forcibly to the remnants of the former state of things; to the few remaining native tribes and the monuments of their ancestors scattered through the land. No man of science, whatever his main interest may be, can be insensible to the vital importance of securing permanent records of these vestiges before they inevitably perish. No astronomer who is properly grateful for the endowment of his own science in time of need can fail to hope that the science of Anthropology may be equally fortunate at a most critical juncture. I have not the means of knowing whether the vanishing opportunities are being properly cared for: I earnestly hope it may be so; but, if it is not, surely this great assembly of men from all sciences and nations could not unite to better purpose than to urge on the American nation the supreme importance of special assistance to Anthropology at the present time. We all have needs, even pressing needs, but the pressure is not usually of this kind. The subject-matter of our investigations is not evanescent; we astronmers, for instance, know that if we must perforce put aside a particular investigation for lack of means, fifty years hence a more fortunate successor will find the eternal heavens little changed for the same purpose. But the anthropologist cannot wait; with him it is now or never, and Science would be a poor thing indeed if we could not be so unselfish as to recognize his needs as more urgent than our own. Is it too much to hope that, even before we leave this hospitable city, we may have some assurance that full justice shall be done in this matter?

It is a familiar fact that there are epochs in the history of a science when it requires new vigour; when new branches are put forth and old branches bud afresh or blossom more plenteously. The vivifying cause is generally to be found either in the majestic form of the discovery of a new law of Nature, or in the humbler guise of the invention of a new instrument of research. The history of Astronomy has been rich in such epochs, notable among them being that when Newton announced to the world the great Law of Gravitation, and that when Galileo first turned his telescope to the skies.

We have within the last half-century been fortunate enough to include another great epoch in astronomical history, characterized by the birth, almost a twin-birth, of two new scientific weapons—the spectroscope and the sensitive film. It is, of course, somewhat difficult and scarcely necessary to assign an exact date for the origin of either of these; the spectroscope was perhaps first systematically used on the heavenly bodies by Huggins, Rutherfurd, and Secchi in the 50's, but we may trace it back to the early work of Fraunhofer, who described the spectrum of Sirius in 1817, or further back to the experiments of Newton with a prism; and the *dry*-plate, which in particular has conferred such benefits on our science, had of course its precursors in the collodion plate or the daguerreotype. But the greater part of the influence on astronomy of both the spectroscope and the photographic method dates from the time when the dry plate was first used successfully, not much more than a quarter of a century ago; and in that quarter of a century there have been compressed new advances in our knowledge which perhaps will compare favourably with the work of any similar period in centuries either past or to come. It is difficult to estimate at their true value historical events in which we play a part, and any review of such a period undertaken now must be necessarily imperfect, for we are advancing so rapidly that our point of view is continually changing. But it is an encouraging thought that obvious difficulties may enhance interest in the attempt nd suggest kindly excuses for its shortcomings.

From the embarrassingly large number of possible topics which the period provides, I have selected that of astronomical photography, and I invite your attention to some characteristic features of the photographic method in astronomy, and some reflections thereupon. It is scarcely possible to avoid repeating much that has been said already, but I hope it will be clear that no claim to originality is advanced; in what follows I wish to claim nothing as mine save its imperfections.

The advantages of the photographic method, which attracted attention from the first, may be grouped under three heads—its power, its facility, and its accuracy. The lines of demarcation are ill-defined, but the classification will help us a little, and I proceed to consider the groups in this order.

The immense *power* of the photographic method as compared with the eye arises from the two facts that (*a*) by the accumulation of long exposures fainter and fainter objects can be detected, and that (*b*) large regions of the heavens can be recorded at the same exposure. No property of the photographic plate has excited more marvel than the former—that it can detect objects too faint to be seen even by our largest telescopes; objects of whose very existence we were in ignorance and should have remained in ignorance. Early successes have been followed up by others more striking as years have rolled on, as better instruments have been devised, and the patience of the watchers has proved equal to greater strain. It is here that the change from the "wet" plate to the "dry" has proved most advantageous. The possibilities with the former were limited to the period during which it would remain wet; with the latter, exposures may be continued for hours, days, even years—not, of course, continually in the case of astronomical photography, for the camera must be closed when daylight approaches; but it can be opened again at nightfall and the exposure resumed without fault. In this way objects of extraordinary faintness have been revealed to us. When Nova Persei had flashed into brilliance in 1901, and then slowly faded, long exposure photographs of its region revealed to us a faint nebulous structure which we could never have seen; they told us that this structure was changing in appearance in a manner which it taxed our ingenuity to explain, and about which speculation is still rife. But a greater triumph was to come; even the *spectrum* of this faint object has been photographed. When we consider that in the spectrum each point of light in the object is enormously diluted by being spread out into a line, the difficulty of this undertaking seemed almost prohibitive; but it was not sufficient to prevent Mr. Perrine, of the Lick Observatory, from making the attempt, and he was deservedly rewarded by success. I may be wrong in regarding this success as the high-water mark in this direction at the present time, and it will probably be surpassed by some new achievement very shortly; but it will serve to illustrate the power of photography in dealing with faint objects.

But may we here pause for one moment to marvel at the sensitiveness of the human eye, which is such that it is, after all, not left very far behind in the race? The eye, sensitive as it is merely to transient impressions, is no match ultimately for the plate, which can act by accumulation. But with similar instruments the plate must be exposed for minutes or even hours to seize the impression of a faint object which the eye can detect at a glance. There seems to be no reason in the nature of things why the eye should not have been surpassed in a few seconds; and in the future the sensitiveness of plates may be increased so that this will actually be the case, even as in the past there was a time when the sensitiveness was so small that the longest exposure could not compete with the eye. But this time is not yet come, and at the present

moment the eye is still in some departments superior to its rival, owing to this very fact, that though it can only see by glances, it can use these glances to good effect. In the study of the planets the more clumsy method of the photographic plate (which, by requiring time for the formation of the image, confuses good moments with bad) renders it almost useless as compared with the eye; and again, we have not as yet used photography for daylight observations of stars.

But there is another direction in which the photographic plate is immensely superior to the eye in power; it can record so much more at once*. In the able hands of Prof. Barnard, Dr. Max Wolf, and others, this property of the plate has been used to record the presence in the sky of vast regions of nebulosity such as, we may safely say, the eye would never have satisfactorily portrayed, not altogether because of their faintness (for in one of his papers Prof. Barnard tells us that he was actually led to photograph such a region because he had become vaguely conscious of it by eye-observation), but because of their diffusion. It is noteworthy that these beautiful photographs were taken with comparatively humble instruments, and we may be as yet only on the threshold of revelations still to be made in this direction.

Secondly, the photographic method represents a great advance in facility of manipulation. A familiar example may be taken from the domain of planetary discovery. In old time, to recognize a new object among numerous fixed stars, it was necessary either laboriously to map out the whole region, or to learn it by heart, so that it was practically mapped in the brain. Now all this labour is avoided; two photographs of the same region, taken without any strain on the memory or the measuring ability of the observer, can at a glance, by a simple comparison, give the information that a strange object is or is not present—information formerly obtained at so much cost. Sometimes, indeed, the cost was so great that the information was not obtained at all. For 15 years Hencke searched without success for a planet, and for nearly 40 years after the discovery of the first four small planets in 1807 no further discoveries were made, though hundreds were constantly crossing the sky, and a dozen new planets are now found every year with little trouble.

* This property has been beautifully illustrated by a lecture-experiment of Prof. Barnard. He throws on the screen a picture of a large nebula which the photographic plate has no difficulty in portraying all at once; but the picture is in the first instance covered up by a screen, except for a small aperture only, and this aperture, he tells his audience, represents all that can be seen by the eye at one time, using the giant telescope of the Yerkes Observatory. By moving the screen about, different portions of the picture may be viewed successively, as also by moving the telescope about in looking at the sky itself. But what a revelation follows when the screen is removed and the full glory of the nebula is exhibited at a single glance! We can well understand that the true character of these objects was hopelessly misinterpreted by the eye using the imperfect method of piecemeal observation which alone was formerly possible.

But though this instance of increase in facility is striking, it is far from being the only one or even the most important. Wherever we require a record of any kind, whether it be of the configuration of stars, or of solar spots, or of the surface of the Moon, or of a spectrum, the labour of obtaining it has been enormously reduced by the photographic method. Think for a moment of what this means in the last instance only—think of the labour involved in mapping one single spectrum by eye-observation; of the difficulty of settling by such a method any doubtful question of the identity of certain lines in the spectrum of a star. A few years ago Dr. McClean announced that he had found oxygen in the star β Crucis. Up to that time this element, so familiar to us on this Earth, had appeared to belong to us alone in the Universe, for in no spectrum had its lines been detected. The proof of its existence in β Crucis depended on the identity of a number of lines in the spectrum with some of those of oxygen; and the measures were sufficiently difficult on a photograph, so that for more than a year the scientific world refused to pronounce a verdict. How long would the case have dragged on if only visual measures had been possible? We may fairly doubt whether a definite conclusion would ever have been reached at all. By the sheer facility of the new method of work we have advanced by leaps and bounds where we could only crawl before.

Thirdly, there has been a great gain in *accuracy* from the introduction of photography; and it is this quality which is above all of value in the science of Astronomy*. The wonderful exactness of the photographic record may perhaps best be characterized by saying that it has revealed the deficiencies of all our other astronomical apparatus—object-glasses and prisms, clocks, even the observer himself.

It has almost been forgotten that in the early days the accuracy of a photograph was doubted. Even now it can scarcely be said that we know definitely the stage of refinement at which we must begin to expect irregular displacements of the images from distortion of the photographic film; but we have learnt that they do not occur in a gross degree, and that other apparatus must be improved before we need turn our attention seriously to errors arising from such a cause. Consider, for instance, what photography has told us about our optical apparatus, which we regard as having reached a high stage of perfection. We are accustomed to think of properly made optical apparatus as being sufficiently similar in all its parts; it is tacitly assumed in the principle of

* Two things may be measured on a photographic plate—the position of an object, or the density of the image; the former being an indication of its position in the heavens, and the latter of its brightness. With the latter topic I do not propose to deal, for the reason that it is in the hands of a much abler and more experienced exponent; but the former alone will provide enough food for reflection.

the heliometer, for example, that one half of the object-glass is sufficiently similar to the other. But a stock adjustment recently adopted in photographing a spectrum for accurate measurement exhibits clearly the errors of this assumption. Photographs are taken of the spectrum through the two halves of the objective; and if they were properly similar the lines in the two halves of the spectrum should fit exactly. A mere glance is usually sufficient to show discordances. It is true that one of the photographs is taken through the thick half of the prism and the other through the thin, so that errors of the prism are included; but these, again, are optical errors. They are, however, not the only sources of error which at present mask photographic imperfections. Glass plates are not flat, and this want of flatness introduces sensible errors. Even with the great improvements in our driving-clocks which were called for immediately photographs were to be taken—with electrical control and careful watching on the part of the observer,—there is apt to creep in a "driving-error" which gives bright stars a spurious displacement relatively to faint. We must get flatter plates, better driving-clocks, and watch more carefully before we can certainly accuse our photographs of a failure in accuracy. Nevertheless, there are indications that we may be near the limit of accuracy even now. Examination of the réseau lines on various plates appears to show small displacements for which no cause has yet been assigned; and the end of our tether may not be far away. But as yet we have not been pulled up short, and there is hope that the warning may be, as on one or two previous occasions, a false alarm.

Such being the accuracy of the photographic method, it is surprising that it should not as yet have been more fully adopted in that field of work where accuracy is of the greatest importance—namely, in what is called fundamental work, with the transit-circle or other meridian instruments. The adoption of new methods is always a slow process and there are at least two classes of difficulties which hinder it. The first class has its origin in the instinctive conservatism of human nature, wherein men of science differ little from their fellows. The second has to do with available capital; and in this respect we are distinctly at a disadvantage compared with other men; for when a new instrument of *general* utility is invented, at once a large amount of capital is invested in working out the details and improving them to the utmost, whereas for a scientific instrument no such funds are available. Think, for instance, of the money spent in perfecting the bicycle, and the time occupied in developing it from the earliest forms to those with which we are now familiar—from the "boneshaker" of the sixties through the high bicycle which we saw 20 years ago, to the modern machine. Think, too, how totally unexpected have been some of the incidents in the history of this machine—such as the introduction of pneumatic tyres, or its use

by ladies *. In the case of such an Instrument, now universally adopted, if rapid development could have been secured by expenditure of money and brains, surely enough of both commodities were forthcoming to attain that end; and yet simplicity and finality have probably not yet been attained in a period of 30 years. When we compare the small amount of money and especially the small number of persons that can be devoted to the perfection of a new scientific method, such as the use of photography in astronomy, it will excite little suprise that progress during the same period of 30 years has been slower. In commerce old machines can be thrown on the scrap-heap when improvements suggest themselves; but who can afford to throw away an old transit-circle? The very fact that it has been in use for many years renders its continued use in each succeeding year the more important from considerations of continuity.

It is doubtless for such reasons as these that little has yet been done in the way of utilizing photography for meridian observation. Although one or two meritorious beginnings have been made, which have sufficed to show that there are no insuperable difficulties in the way, up to the present moment no meridian instrument of repute is in regular work using the photographic method. And this fact cannot, after all, be completely explained by the reasons above mentioned. Opportunities for setting up costly new instruments do not occur frequently in astronomy, but they do occur. In the last decade, for instance, large transit-circles have been set up both at Greenwich and the Cape of Good Hope; but in neither instance has any attempt been made to adopt the photographic method. The Washington Observatory was reconstructed well within the period since the great advantages of photography have been recognized; and yet not even in the United States, the land of enterprise, was a start then made in a direction in which it is certain that we must some day travel. That day has probably been deferred by the stimulation of competing methods which a new one brings with it. When electric light was first introduced into England, the gas companies, stimulated by the stress of competition, adopted a new and improved form of light (the incandescent gas) which put them at a much less serious disadvantage compared with their new rival. So when photography began to show what new accuracy was attainable in measurement of star-positions, it would almost seem as if the devotees of the older visual methods were compelled to improve their apparatus in order not to be left wholly behind in the race. The registering Micrometer † was produced by Messrs. Repsold, with the astonishing result that the troubles from personal

* I have in my possession a copy of a work of reference on cycling, dated no earlier than 1887, in which it is carefully stated as a deliberate conclusion that ladies will never use the machine to any great extent.

† We have been accustomed hitherto to determine the position of a star by observing the instant when it crossed a fixed wire; but it has long been known

equation, which have so long been a difficulty in all fundamental work, have practically disappeared.

This beautiful invention has placed the eye once more in a position actually superior to the photographic plate; for with the eye we can observe stars in daylight, and so secure information of great importance, whereas no photographic method of doing this has, as yet, been devised. And there is also the fact that for faint stars a long exposure would be required for what the eye can accomplish in a few seconds.

Thus in one or two astronomical channels the effects of the rising tide of photography have scarcely yet been felt; but into all the others it has swept with ever growing force. Looking back over the 30 years of advance, we may be well satisfied. With more funds, and especially with more men, no doubt more could have been done: let us even admit that we might have done better with the same funds and the same limited staff. But on the whole we have been fortunate. At a critical time, when we might have felt the want of larger endowments acutely, the need was almost anticipated by a stream of benefaction. If this stream had its chief source in the United States, its beneficial effects have poured over the whole world; and induced currents have begun to flow elsewhere. We may reflect with thankfullness how much harder our advance might have been but for the noble gifts to the Harvard, the Lick, and the Yerkes Observatories: and earnestly hope that the cheerful expectations of a great American astronomer, that these are but the foreshadowing of much larger gifts to science, may be adequately realized.

May I now turn to one or two of the problems with which this new development of our work has brought us face to face? They

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that two different observers record systematically different instants—they have a personal equation. Recently we have learnt that this personal equation avries with the brightness of the star observed, and with other circumstances, and to make the proper corrections for it has severely taxed our ingenuity and involved much work. Before the invention of photography, we might well bear this with patience, since it seemed to be inevitable; but the photographic plate, which is free from human errors, offers a way of escape from all troubles—at the expense, no doubt, of some little experimenting, but with every prospect of speedy success. Eye observation, which had borne this burden so long, must get rid of it if it was to march alongside the untrammelled photographic method; and the suprising thing is that it has actually done so. The adopted device is extremely simple: replace the fixed wire which the star crosses by a wire which moves with the star and registers its own movements. The registering is done automatically; but the motion of the wire is controlled by the observer and there is still room for a new form of personal equation in this human control. But none manifests itself, probably for the reason that we no longer have two senses concerned, but only one. In recording the instant when a star crosses a wire we employ either the eye and the ear, or the eye and the sense of touch; and personal equation arises from the different co-ordination of the two senses in different people. But in making the wire follow the star, the eye alone is concerned, and there is no longer any room for difference in "latent period" or other co-ordination of two senses.

are numerous and serious, and it is impossible to consider many of them, perhaps even the most important of them. One of the most pressing is the problem of rendering generally accessible the vast accumulations of material for study that have been suddenly thrust upon our attention. How are our photographs to be stored, preserved, and published? Even now troubles have gathered, and time will only multiply them. It is many years since Prof. Pickering drew attention to the difficulties in storing the photographic plates taken at the Harvard Observatory; when many thousands of photographs have been accumulated, not only the space they occupy but the actual weight of glass is an embarrassment. And there seems to be no doubt concerning the duty of accumulation. May I confess an early and mistaken view which I formulated on this matter? I reasoned thus:—The proper moment for making use of a photograph taken last night is to-day. It is useless to defer the examination until to-morrow, for there will then be new photographs claiming attention. Hence it is unscientific to take more photographs than can be dealt with immediately. This seemed to be a plausible argument and to show a way out of the difficulty, for if a photograph had once been adequately examined, it need not be stored so carefully, and there would not in any case be many to store. But Prof. Pickering has demonstrated many times over that the view is untenable. By taking photographs almost recklessly and without any hope of dealing with even a fraction of them, he has created the possibility of tracing the history of celestial events *backwards*. When new objects are discovered he can go to his shelves and tell us how long they were visible previous to discovery; and this information is so valuable that we must certainly arrange our future plans with reference to it. It is quite certain that we must be prepared to deal with enormous accumulations of plates, to store them in proper order, and to catalogue them; and if it has already been found difficult to do this for the collection of a single observatory during twenty years, what can we look for in the centuries to come?

Possibly the second difficulty, that of preservation, may be an antidote to the first. It is by no means certain that our photographs will last long; and if not, there will be a natural limit to the time during which they need be kept. Sir William Crookes has, however, reminded us that by toning them, by substituting sturdy gold for the perishable silver, we may prolong their life indefinitely, though this will, of course, sensibly increase the cost of each plate. As yet I have not heard of any toning process being systematically adopted. Our course is, however, comparatively clear in this direction; it would seem imperative that a selection of the earliest photographs at any rate should be carefully toned, so that they may be available for comparison in years as far distant as possible. Although this is a matter of detail, it seems to me to compare in importance with almost any practical question which may claim the attention of astronomers; and if some

decision of the kind were the only outcome of this gathering, I think we might be well content with the result.

The question of publication is chiefly one of funds, and is only worthy of special remark because these particular funds are so often forgotten in planning enterprises. I need not labour the point, for the experience of any astronomer will supply him with plenty of instances. The difficulties of publication have much in common with those of storage; they will increase year by year, and even when the money for printing has been found, the storage of publications received from other observatories will itself become an embarrassment. There is, however, one way in which some of the stress may be relieved, namely by efficient cataloguing. If we have before us a list of all the photographs existing in the world, and know that we can send for a copy of any one of them which may be required, it is no longer necessary to have copies of all. This applies, of course, to other publications as well; and though we may take some time to grow out of the sentimental desire for a complete library, and though the existence of a few such complete institutions may always be desirable, I venture to think that many observatories will ultimately be driven to the plan of acquiring only what is certainly and immediately useful, depending on temporary loans from central institutions for other material.

But there is a class of problems differing totally in character from these practical questions of storage and preservation of plates. A period of suddenly increased activity such as we have been passing through in astronomy is not without important effects on astronomers themselves. The human element in our scientific work is sometimes overlooked and generally accorded only a subordinate importance; but coming as I do from an old university devoted to the Humanities, I may be perhaps forgiven for calling attention to a few human considerations. In the first place, I have felt some anxiety lately for that very important body of astronomers who are sometimes called amateurs, though the name is open to criticism—those whose opportunities for work are restricted to a more or less limited leisure. It is a body which is somewhat sensitive to the feeling that astronomical work has gone beyond them, that in the presence of large instruments and of the special knowledge acquired by those using them, their own efforts and their own humbler instruments are no longer of any value. If I am right in supposing that this feeling has been called into existence lately by the rapid advances made in photography, it is certainly not for the first time. At previous epochs this diffidence has found expression and has, I am glad to say, been met by careful contradiction; but it is necessary to repeat the expostulation again and again, for the anxiety is apt to crop up with every new development of astronomical activity.

The *early* days of photography were better ones than usual for the amateur; indeed the introduction of the photographic method is largely due to the work of such men as Rutherfurd and Draper

in America, De la Rue and Common in England. But now that we have passed beyond the stage when each new plate taken was a revelation; now that we are tolerably familiar with, at any rate, the main types of possible photographs which can be taken with modest apparatus; more especially now that we have begun to discuss in elaborate detail the measurement of star-positions or of stellar spectra, the old shyness is beginning to crop up again. But it is of the utmost importance that this shyness should be zealously overcome. Perhaps, after all, it is not sufficient to assert that there is still good work for amateurs to do, nor even to mention a few instances of such work urgently required; perhaps it should be made easier for them to follow what is being done. Especially do we want more and better *books*, written by the best men in each subject. The original memoir, though it may be the proper form of publication for the workers themselves, does not satisfy all requirements. There is much to be done in the way of extension and collation before the work can be presented in a form attractive to those who would gladly keep in touch with it if the process could be made a little easier. Huxley was constantly urging scientific men that it was not sufficient to attain results; they must also express them in an intelligible and attractive form. Of course it is not easy for the same man to do both. There are few who could have determined, like Schiaparelli, that the period of rotation of the planet Mercury was 88 days instead of 1; but there are fewer still who, after making the discovery, could have given the beautiful lecture which he gave before the King of Italy, developing fully in attractive detail the consequences of the discovery; and yet it is probably true that many more could make, at any rate, an attempt in this direction, if adequate opportunity and inducement were provided. Could not a part of the sums available for the endowment of research be devoted to the endowment of text-books? It is of course an inducement to write such a book that it is a good thing well done; but in the case of a scientific worker this is scarcely sufficient, because the same could be said of his continuing his particular work. If we ask him to pause, and render the treasures he has collected accessible to others, there must be some additional inducement. Publishers are not able to offer pecuniary encouragement, because books of the type I have in mind would not appeal to a very large public. But why should they not be subsidized? I do not think it need be a very costly business, if the money were placed in the hands of a central body to issue invitations for books to be written. An invitation would be in itself a compliment; and the actual pecuniary value of the inducement would shrink in importance, just as the actual amount of gold in a medal awarded by one of our leading scientific societies is not very seriously regarded. It may be objected that to ask the best men to write text-books is to set them to inferior work, and so to delay true scientific progress; but are we sure that the real march of science is being delayed? There are pauses in a journey which

merely waste time; but there are others without which the whole jonrney may be delayed or prevented, as when a man should neglect to rest and feed the horse which carries him.

But the development of photography has brought with it much more than a recurrence of diffidence in some amateurs; it has foreshadowed a serious rearrangement of astronomical work generally —a new division of labour and a new system of cooperation. To quote one notable instance: a very small number of observatories could take enough photographs to keep the whole world busy examining or measuring them, and we are already face to face with the question whether this is a desirable arrangement. Let me give a concrete example of this modern situation. In the winter 1900–1 the small planet Eros offered a specially favourable opportunity for determining the solar parallax, and some thousands of photographs were taken at a number of observatories for the purpose. It is not yet very clear how a definitive result will be obtained from the mass of material accumulated, most of which is being dealt with in a very leisurely manner: but a small portion of it has been discussed by Mr. A. R. Hinks, of Cambridge, and one of the many important results obtained by him in a recently-published paper (Mon. Not. R. A. S., June 1904) is this: that the plates taken at the Lick Observatory are susceptible of such accurate measurement, and so numerous, that a determination of the solar parallax from them alone would have a weight nearly equal to that from the whole mass of material. If the Lick plates can be measured and reduced, it will not much matter if all the others are destroyed. Whence we may deduce two conclusions: firstly, that it is eminently desirable that these beautiful pictures should be measured and reduced as soon as possible; secondly, that we must consider future plans of campaign very carefully if we are to avoid waste of work and discouragement of workers. It is tolerably easy to reach the first precise conclusion; I wish it were easier to arrive at something more definite in regard to the second. It seems clear that we may expect some readjustment of the relations between the better-equipped observatories and those less fortunate, but it is not at all clear what direction that readjustment should take. One possibility is indicated by the instance before us: the discussion of the Lick photographs was not conducted at the Lick Observatory, but at Cambridge: the price paid for the fine climate of Mount Hamilton is the accumulation of work beyond the powers of the staff to deal with, and the new division of labour *may* be, for the observatories with fine climates and equipment to take the photographs, and astronomers elsewhere to measure and discuss them. Prof. Kapteyn has set us a noble and well-known example in this direction, and in view of the pressing need for a study of many photographs already taken, it is to be hoped that his example will be followed, especially in cases similar to his own, where no observatory is in existence. If in such cases the investigator will set up a measuring

machine instead of a telescope, he will deserve the gratitude of the astronomical world.

But the case is not so clear when a telescope is already in existence. Mr. Hinks had a fine telescope at Cambridge, and it required some self-denial on his part to give up observing for a time in order to discuss the Lick photographs and others. If the accumulations already made, and others certain to be made in the future, are to be dealt with, this kind of self-denial must certainly be exercised, but it does not seem quite clear that it should always fall to the lot of those with a modest equipment. Considerations of strict economy might suggest this view, but there is a human side to the argument which is not unimportant. The danger that the minor observatories should feel their work unnecessary is even graver than the similar possibility in the case of amateurs already mentioned, and calls for prompt attention from astronomers generally if it is to be averted. It is the more serious because of another set of considerations of a quite different kind, viz., the funds available for research show a rather alarming tendency to accumulate in the hands of a few large observatories, leaving many astronomers who could do useful work without the means of doing it. A conspicuous example is afforded by the present state of the work for the Astrographic Chart initiated in Paris seventeen years ago. On the one hand, a few of the large observatories have easily acquired funds not only for taking and measuring the plates and printing the results, but for publishing an expensive set of charts which will be of very little use to anyone; on the other hand, some of their colleagues have found the utmost difficulty in getting funds for even taking the plates; others have got so far but cannot proceed to measure them; and very few indeed have yet funds for printing. If there had been a true spirit of cooperation for the general good in this enterprise, surely some of the funds being squandered on the comparatively useless charts would have been devoted to the proper completion of the only part of the scheme which has a chance of fulfilment. I do not mean to imply that this would have been an easy matter to arrange, but it is noteworthy that no attempt in this direction has been made, and that as a consequence a promising scheme is doomed to failure in one important particular. For though the survey of the whole sky to the 11th magnitude may some day be completed, it will be sadly lacking in homogeneity. Some sections are finished before others are begun, so that in the vital matter of epoch we shall have a scrappy and straggling series instead of a compact whole.

Cooperation in scientific work, the necessity of which is being borne in upon us from all sides, is nevertheless beset with difficulties, and no doubt we shall only reach success through a series of failures, but we shall reach it the more rapidly if we note carefully the weaknesses of successive attempts. In the particular scheme of the Astrographic Chart, I think an error which should

be avoided in future was made by those who have access to the chief sources of astronomical endowment. They have made the enterprise doubly difficult for their colleagues: firstly, by setting a standard of work which was unattainable with limited resources; and secondly by depleting the reserves which might have gone to assist the weaker observatories.

It is easier to draw attention to these modern tendencies than to suggest a remedy for them. It may, perhaps, be questioned whether a remedy is either possible or necessary; it may be urged that it is both inevitable and desirable that astronomical observation should gravitate more and more to those well-equipped observatories where it can be best conducted, and that new resources will obtain the greatest results when added to a working capital which is already large. From the purely economical point of view of getting results most rapidly, these conclusions may be true. But if we look at the human side of the question I hope we shall dissent from them; if we think first of astronomers rather than of the accumulation of astronomical facts, I hope we shall admit that something must be done to check the excessive specialization and the inequalities of opportunity towards which there is a danger of our drifting. We cannot afford the division of astronomers into two types: one isolated in a well-equipped observatory in a fine but rather inaccessible climate, spending his whole time in observing or taking photographs; another in the midst of civilization, enjoying all the advantages of intercourse with other scientific men, but with no telescope worth using, and dependent for his material on the observations made by others. Some division of labour in this way is doubtless advantageous, but we must beware lest the division become too sharply pronounced. Will it be possible to prevent its undue growth by some alternation of duties? Can the hermit observer and the university professor take turn and turn about to the common benefit? The proposal is perhaps a little revolutionary, and has the obvious disadvantages of inconvenience and expense at the epochs of change; but I do not think it should be set aside on these grounds.

I must admit, however, that I am not ready with a panacea. It has been chiefly my object to draw attention to some modern tendencies in astronomical work, hoping that the remedies may be evolved from a general consideration of them. Such questions of the relationship of the worker to his work are even harder to solve than those we meet with in the work itself. But there is at least this excuse for noticing them on an occasion like the present, that they are, to some extent, common to all departments of knowledge, and our difficulties may come to the notice of others who have had occasion to consider them in other connections and may be able to help us. Or, again, we may take the more flattering view that the human problems of Astronomy to-day may be those of some

other science to-morrow ; for Astronomy is one of the oldest of the sciences, and has already passed through many stages through which others must pass. In any case we must deal with these problems in the sight of all men ; and of all the consequences entailed by our lately-acquired opportunities, none are more interesting and none can be more important to us than those affecting the astronomer himself.

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